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Effects of rice or wheat residue retention on the quality of milled *japonica* rice in a rice–wheat rotation system in China

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A B S T R A C T

In rice–wheat rotation systems, crop straw is usually retained in the field at land preparation in every, or every other, season. We conducted a 3-year-6-season experiment in the middle–lower Yangtze River Valley to compare the grain qualities of rice under straw retained after single or double seasons per year. Four treatments were designed as: both wheat and rice straw retained (WR), only rice straw retained (R), only wheat straw retained (W), and no straw retained (CK). The varieties were Yangmai 16 wheat and Wuyunjing 23 *japonica* rice. The results showed contrasting effects of W and R on rice quality. Amylopectin content, peak viscosity, cool viscosity, and breakdown viscosity of rice grain were significantly increased in W compared to the CK, whereas gelatinization temperature, setback viscosity, and protein content significantly decreased. In addition, the effect of WR on rice grain quality was similar to that of W, although soil fertility was enhanced in WR due to straw being retained in two cycles. The differences in protein and starch contents among the treatments might result from soil nitrogen supply. These results indicate that wheat straw retained in the field is more important for high rice quality than rice straw return, and straw from both seasons is recommended for positive effects on soil fertility.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important crops in the world, and provides much of the energy, protein, and other nutrients for half of the world population [1]. Rice quality is determined by genetic factors, environmental factors, and cultivation measures [2]. Studies conducted in recent years indicate that increased temperature, soil moisture, and

Abbreviations: SOM, soil organic matter; TN, total nitrogen; TP, total phosphorus; TK, total potassium; AP, available phosphorus; AK, available potassium

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fertilizer affect rice quality. However, research on the relative effects of rice versus wheat residue retention on subsequent rice grain quality in rice–wheat rotation systems is rare [3–12].

Rice–wheat rotation is the dominant practice in the middle-lower Yangtze River area of China [13]. The return of crop residue to fields is an important way to conserve and sustain soil productivity [14,15]. Xu et al. [11] reported the effect of wheat residues on the quality of direct-seeded rice, and Liu et al. [8] described the effects of no tillage and wheat straw retention on rice quality in a regional experiment. Normally, most of the residue decomposes before rice transplanting when rice straw is returned to the field in the wheat-growing season [16]. Additionally, the possible impacts of rice straw on rice quality may be minor and short term. There are no reports regarding the effects on rice quality of returning rice straw in a rice–wheat rotation system. Indeed, the effects of rice and wheat straw in rice–wheat rotations on rice quality are unclear. Moreover, the full mechanical incorporation of the straw in each season or every other season may be the main method for residue management in rice–wheat rotation systems in the future. Thus, it is necessary to understand the effects of wheat straw, rice straw, and their interactions on rice quality. The present research comprised a 3-year, regional experiment in a wheat–rice rotation system which was conducted to support high quality and efficient rice cultivation by evaluating the effects of retention of rice straw, wheat straw, and a combination of both straw types on subsequent rice grain quality.

2. Materials and methods

2.1. Experimental site

The field experiment was performed at Danyang Experimental Station of Nanjing Agricultural University, Jiangsu province (31°54′31″N, 119°28′21″E), an area where the primary cropping regime is an annual paddy rice–winter wheat rotation. The soil type is a periodically waterlogged paddy soil. The characteristics of the soil before the experiment were: SOM, 17.15 g kg^{-1}; TN, 0.973 g kg^{-1}; TP, 0.5 g kg^{-1}; TK, 10.99 g kg^{-1}; AP, 13.6 mg kg^{-1}; and AK, 93.5 mg kg^{-1}. In addition, the soil fertility for different treatments in 2012 is described in Table 1.

2.2. Experimental treatment and design

The field experiment started with the wheat–growing season in October 2009 and ended after rice harvest in October 2012, encompassing three cycles and six crop seasons. The analyses for the present study were conducted after the rice season in the third year of the rotation. A randomized split-plot design with three replications was used. Four straw-retention treatments were applied: continuous retention of wheat and rice residues in every season (WR), rice residues only retained in every wheat season (R), (3) wheat residues only retained (W), and a control with no residue retention (CK). Each plot, 7.0 m × 4.5 m in size, was separated by a ridge. Combined harvesters left all residues as short pieces of rice or wheat straw on the soil surface of each experimental plot, and the pieces were incorporated within 0.15 m of the top soil before seeding (wheat) or transplanting (rice); in other plots residues were removed from the plots as required. The nutrient contents of nitrogen, phosphorus and potassium were respectively 1.29%, 0.30%, and 3.23% in rice straw; and 0.58%, 0.04%, and 2.77% in wheat straw. The wheat variety Yangmai 16 was seeded on 30 October 2009, 9 November 2010, and 16 November 2011 and harvested on 5 June 2010, 7 June 2011, and 31 May 2012, respectively. The rice variety Wuyunjing 23 was sown in seedbeds, transplanted, and harvested on 25 May, 26 June, and 2 November 2010; 27 May, 24 June, and 3 November 2011; and 28 May, 27 June, and 31 October 2012, respectively. The wheat seeding rate was 225 kg ha^{-1}, and the density of rice transplants was 30.0 cm × 13.3 cm. Fertilizer was applied in the manner used locally for high production (225–105–105 kg ha^{-1} N–P_2O_5–K_2O in the wheat season, and 300–150–240 kg ha^{-1} N–P_2O_5–K_2O in the rice season). Water management was set as wet–dry–wet–dry, as described in Hou et al. [17].

2.3. Sample collection and measurements

At maturity, approximately 100 panicles of similar maturity were harvested from each replication. The samples were dried naturally and then dehulled. Brown rice was milled for 90 s with a JNMJ3 rice polisher (Taizhou Grain Industry Instrument Corp, Zhejiang, China), and ~10% of the outer layers were removed. The milled rice was ground in a stainless steel grinder for 3 min, and the resulting powders were used for chemical analysis. The traits measured included appearance quality (grain length, grain width, ratio of kernel length to width (L/W), and grain thickness), milling quality (brown rice recovery, milled rice recovery, and head-milled rice recovery), physico-chemical properties (amylose content, amylopectin content, starch content, and RVA profiles), and protein components.

Quality traits, including grain length, width, and thickness, and brown rice, milled rice, and head-milled rice recovery rates, amylose content, and starch content were measured according to China National Standards (GB/T 17891-1999).

Table 1 – Soil fertilities (0–20 cm) in different straw retention treatments in 2012.

Treatment	pH	SOM (g kg^{-1})	TN (g kg^{-1})	TP (g kg^{-1})	TK (g kg^{-1})	AP (mg kg^{-1})	AK (mg kg^{-1})
WR	6.28 a	17.80 a	1.11 a	0.40 a	13.98 a	14.93 a	111.77 a
R	6.17 ab	17.62 a	1.08 a	0.50 a	13.78 a	19.07 a	108.58 a
W	6.05 b	17.71 a	1.07 a	0.47 a	13.41 a	14.38 a	101.73 a
CK	6.25 ab	17.19 b	0.97 b	0.48 a	13.96 a	14.87 a	82.42 b

Soil fertilities were measured in the 2012 crop seasons. Means followed by different letters are significantly different according to least significant difference (LSD) at $P = 0.05$.

Protein fractions were separated and analyzed according to the method reported by Liu et al. [18]. Four protein fractions were sequentially extracted in the order of albumin, globulin, prolamin, and glutelin. Total protein concentration was calculated as the sum of the four proteins.

RVA profiles were determined using a Rapid Visco Analyser (Australia) following the procedure of the American Association of Cereal Chemists [19]. Data were recorded with matching software (TCW) and included the peak viscosity, hot viscosity, cool viscosity, peak time, gelatinization temperature, breakdown viscosity, setback viscosity, and consistency viscosity in cp (centipoises) units.

2.4. Statistical analysis

Analysis of variance was carried out with the SPSS (Ver. 16.0) statistical software (Statistical Graphics Corp., Princeton, NJ). F-values were calculated using the "factorial analysis" program. Means of treatments were compared using the least significant difference (LSD) test at the 0.05 probability level.

3. Results

3.1. Appearance quality and milling quality

No significant effects on milling quality indicators (brown, milled, and head-milled rice recovery rates) were observed among treatments. Grain length and width were slightly higher in the CK than in the straw residue treatments. In contrast, grain thickness varied significantly among the four treatments, with the highest value for WR and the lowest value for CK (Table 2). These results indicated that crop straw retention had no significant effect on rice appearance or milling quality.

3.2. Starch content

Several obvious differences in the starch content of milled rice were detected among the straw-retention treatments, including significant differences in amylopectin and starch contents (Table 3). However, amylose content did not show significant differences among treatments (Table 3). The amylopectin and starch contents of treatment W were the highest of the four treatments and differed significantly from those of the R and CK treatments ($P < 0.05$, Table 3). The WR and W treatments did not differ significantly, but showed a greater difference than that between the WR and R treatments. Amylopectin and starch contents in treatment R were less than in the CK, but the differences were not significant. The amylopectin and starch contents were both reduced in the following order: W > WR > CK > R.

Table 3 – Effect of straw retention type on starch content of milled rice.

Treatment	Amylase content (%)	Amylopectin content (%)	Starch content (%)
WR	17.06	63.29 ab	80.35 ab
R	16.97	60.98 c	77.95 c
W	17.03	64.12 a	81.15 a
CK	16.71	61.81 bc	78.52 bc
		F-value	
R	0.227	1.346	0.946
W	0.468	10.506 **	12.747 **
W * R	0.145	0	0.030

Means followed by different letters are significantly different according to least significant difference (LSD) at $P = 0.05$. F-values were calculated by factorial analysis.
** $P < 0.01$.

Factorial analysis indicated that wheat straw retention significantly ($P < 0.01$, Table 3) increased the amylopectin and starch contents. However, the effects of rice straw retention alone and of combined rice and wheat straw retention were not statistically significant ($P > 0.05$, Table 3).

3.3. Protein components

The effects of the straw retention treatments on protein components of milled rice are shown in Table 4. Neither the albumin nor gliadin to glutenin ratio varied significantly ($P > 0.05$, Table 4). However, globulin, gliadin, glutelin, and protein contents differed significantly among the four treatments ($P < 0.05$, Table 4) and were the highest in treatment R and the lowest in treatment W. Globulin, gliadin, glutenin, and protein levels all decreased with the treatments in the order: R > CK > WR > W.

Factorial analysis indicated that wheat straw incorporation significantly ($P < 0.05$ or 0.01, Table 4) decreased the globulin, gliadin, glutenin, and protein contents, whereas rice straw incorporation significantly ($P < 0.05$, Table 4) enhanced the glutenin and protein contents. In contrast, the combined incorporation of the wheat and rice straws produced no significant changes in any of the components ($P > 0.05$, Table 4).

Table 2 – Effect of different straw retention treatments on rice appearance quality (grain shape) and milling quality.

Treatment	Milling quality			Grain shape			
	Brown rice rate (%)	Milled rice rate (%)	Head milled rice rate (%)	Grain length (cm)	Grain width (cm)	Grain thickness (mm)	Grain length/width ratio
WR	85.43 a	71.55 a	65.69 a	0.557 a	0.317 a	2.247 a	1.77 a
R	85.51 a	71.68 a	66.76 a	0.553 a	0.317 a	2.215 ab	1.75 a
W	85.36 a	71.74 a	67.20 a	0.555 a	0.314 a	2.212 ab	1.77 a
CK	85.76 a	72.15 a	67.45 a	0.558 a	0.320 a	2.207 b	1.74 a

Means followed by different letters are significantly different according to least significant difference (LSD) at $P = 0.05$.

Table 4 – Effect of straw retention type on protein components of milled rice.

Treatment	Albumin (%)	Globulin (%)	Gliadin (%)	Glutenin (%)	Protein (%)	Gliadin to glutenin ratio
WR	0.382	0.669 b	0.832 bc	6.524 ab	8.411 ab	0.128
R	0.395	0.700 a	0.884 a	6.976 a	8.954 a	0.129
W	0.387	0.672 b	0.809 c	6.142 b	8.010 b	0.132
CK	0.371	0.695 a	0.854 ab	6.523 ab	8.443 ab	0.131
			F-value			
R	0.889	0.016	3.528	5.290 *	5.899 *	1.062
W	0.017	17.012 **	11.524 **	5.241 *	6.739 *	0.000
W * R	1.895	0.407	0.055	0.039	0.086	0.083

Means followed by different letters are significantly different according to least significant difference (LSD) at $P = 0.05$. F-value was calculated by factorial analysis.
* $P < 0.05$.
** $P < 0.01$.

3.4. Starch pasting properties

The effects of the different residue treatments on starch pasting properties of rice were marked (Table 5). One-way analysis of variance showed that differences among the treatments for hot viscosity, peak time, breakdown viscosity, and setback viscosity were not statistically significant ($P > 0.05$, Table 5), whereas the values of peak viscosity, cool viscosity, gelatinization temperature, and consistency viscosity varied significantly ($P < 0.05$, Table 5). Peak viscosity, cool viscosity, and consistency viscosity were significantly increased in the WR and W treatments, which showed significantly lower gelatinization temperatures compared to the CK treatments. In addition, the peak viscosity, cool viscosity, hot viscosity, consistency viscosity, and breakdown viscosity were decreased and the gelatinization temperature was increased in treatment R; however, the differences were not statistically significant compared to the CK.

The factorial analysis indicated that retention of wheat straw significantly ($P < 0.05$ or 0.01, Table 5) increased the peak, cool, and consistency viscosities and decreased the gelatinization temperature of rice; however, rice straw and combined rice and wheat straw treatments had no significant effect ($P > 0.05$, Table 5).

3.5. Coefficients of variation of different quality indices

To verify the most important factors affecting the quality of the milled rice, we analyzed the coefficients of variation (CVs) for the above factors that differed significantly among the residue treatments. The results (Fig. 1) indicated that protein components were the most important of these factors. Traits of secondary importance were starch content and starch pasting properties (RVA). The coefficients of variation for different traits decreased in the order: glutenin > protein > gliadin > peak viscosity > amylopectin > cool viscosity > consistency viscosity > globulin > starch > gelatinization temperature (Fig. 1).

4. Discussion

The results of the present study showed that retention of wheat residues had no significant effects on appearance quality or milling quality compared to the CK (Table 2). This was supported by the results of Liu et al. [8], but not by those of Xu et al. [11]. The discrepancy could be caused by different cultivation and residue incorporation methods employed in the studies [20]. We also found that treatments WR and R had

Table 5 – Effect of straw retention type on starch pasting properties (RVA) of milled rice.

Treatment	Peak viscosity (cP)	Hot viscosity (cP)	Cool viscosity (cP)	Peak time (min)	Gelatinization temperature (°C)	Break down (cP)	Setback (cP)	Consistency viscosity (cP)
WR	1802.5 a	1215.3	2225.7 a	6.21	88.68 b	587.17	423.17	1010.3 a
R	1705.0 b	1148.7	2124.3 b	6.22	89.70 a	556.33	419.33	975.7 b
W	1756.7 ab	1150.3	2172.5 ab	6.18	88.87 b	606.33	415.83	1022.2 a
CK	1717.2 b	1149.0	2151.7 ab	6.16	89.33 ab	568.17	434.50	1002.7 ab
				F-value				
R	0.509	1.536	0.258	1.506	0.200	0.888	0.104	3.755
W	8.430 **	1.699	5.778 *	0.018	11.823 **	4.400 *	0.374	7.307 *
W * R	1.511	1.568	2.509	0.167	1.694	0.050	0.860	0.573

Means followed by different letters are significantly different according to least significant difference (LSD) at $P = 0.05$. F-value was calculated by the factorial analysis.
* $P < 0.05$.
** $P < 0.01$.

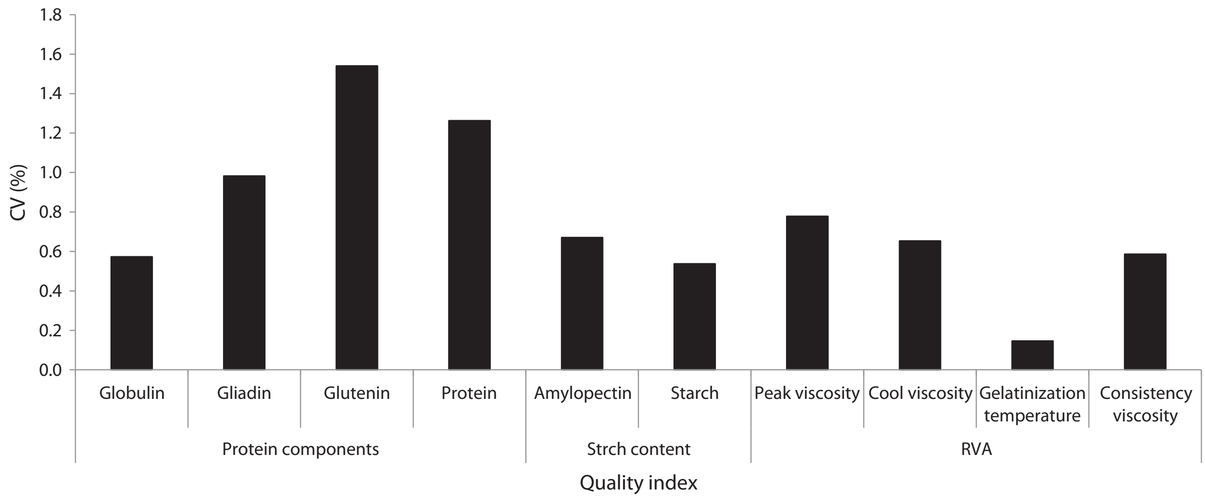

Fig. 1 – Coefficients of variation of different quality indices following different straw retention types.

no significant effects on appearance quality or milling quality (Table 2). These results indicate that the crop straw (rice, wheat) residues had no significant effect on the appearance quality or milling quality.

Our results showed that the peak viscosity, cool viscosity, and breakdown viscosity were significantly increased whereas gelatinization temperature and setback viscosity were significantly decreased in treatment W compared to the CK (Table 5). These changes should be favorable for improved cooking and eating qualities [21–24]. The results also showed that the protein content for treatment W was significantly decreased as indicated by reduced globulin, gliadin, and glutenin contents compared to the CK (Table 4). This is also favorable for improved cooking and eating qualities [21–24]. In addition, the results indicated that the mutual effect of rice and wheat straw on rice quality was not significant. Treatment WR had a similar effect to treatment W. Compared to W, R had the opposite effect on the qualities of succeeding rice grain, although the differences (starch content, starch pasting properties) were not statistically significant between R and the CK. These results indicate that wheat residue retention is conducive to the improvement of rice quality, whereas rice residue retention has a negative effect.

The coefficients of variation (CVs) for rice quality characters indicated that straw retention had a greater effect on protein content than starch content and RVA profile parameters (Fig. 1). Lim et al. [25] found that protein played a critical role in determining pasting characteristics of starch, showing a negative correlation to peak viscosity of starch paste, but a positive correlation to pasting temperature. Protein content is an important index of rice quality [26,27]. Most of the nitrogen used by the rice plant is absorbed during the vegetative growth stage [28,29]. However, some of the soil nitrogen is fixed during residue decomposition [30], leading to lower nitrogen accumulation in rice plants than in the CK with no wheat residue retention (WR, W). Yoshida [31] reported that when more ammonia is absorbed, more carbohydrate is consumed to provide α-oxoalutarate; consequently, less carbohydrate is accumulated in the plant. When ammonia absorption is decreased, surplus photosynthates accumulate as starch and sugars [31]. Soil nitrogen fixation during decomposition may be an important reason for the differences in rice quality although the soil fertility increased when wheat residues were retained. Tang et al. [32] studied the effects of different soil nutrient elements on rice quality using six different paddy soils under the same bio-climatic conditions and found that there were significant correlations between rice quality and soil nutrients, such as organic matter and nitrogen content. Xia et al. [33] drew the same conclusions. Furthermore, many previous studies have pointed out that nitrogen is an important factor for rice quality [34,35]. In addition, Liu et al. [16] found that the residual level of incorporated rice straw after decomposition for a single wheat season was 60%. As shown in Table 1, rice straw incorporation significantly increased the soil organic matter, total nitrogen and available potassium contents as the residue decomposed (nutrient content of nitrogen, phosphorus, and potassium was 1.29%, 0.30%, and 3.23% in rice residue). Therefore, we believe that the changes in rice quality for treatment R may be caused by increased soil fertility (Table 1). Hence, the rice quality difference may be caused by differences in the rates of decomposition of rice compared to wheat straw in different seasons.

It should be noted that the amylase content did not vary significantly among the treatments, but amylopectin content was significantly increased in treatment W (Table 3). Cai et al. [36] and He et al. [37] reported that the chain length distribution of debranched amylopectin affects rice quality. Typically, better taste is correlated with a higher content of short-chain components in amylopectin, whereas a worse taste is associated with increased long-chain components [36]. Thus, the amylopectin content may increase after retention of wheat straw because of the increases in short-chain (Fr III) versus long-chain [Fr (I + II)] components. According to this interpretation, the starch grains gelatinized more fully in treatment W than in the CK and led to an improvement in cooking quality. These processes are closely related to the enzymes that branch and debranch starch [38].

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